Interaction dominated transport in 2D conductors: from degenerate to partially-degenerate regime.

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Recent advances in the fabrication of ultra clean two-dimensional (2D) semiconductor systems make it possible to explore the regime, where the interparticle collisions dominate over the impurity and phonon scattering. In general, a system with a simple parabolic spectrum is a Galilean invariant electron liquid, while, as expected, a system with two types of charge carriers that differ in sign and/or effective mass lacks the Galilean invariance. Indeed in non-Galilean-invariant liquids the colliding carriers have either opposite charge sign or different spectra, so the net current is not proportional to the total momentum of particles. The strong mutual friction between electrons and holes in a degenerate 2D semimetal leads to the resistivity $\sim T^2$. The nodegenerate limit has been explored in a single layer and bilayer graphene, where e-h pairs are thermally excited.

An interesting and important physics is expected to take place when plasma is partially degenerate: electrons are distributed according to the Fermi statistics, while the ions obey the Bolztmann statistics. The physics associated with the hydrodynamics in a partially degenerate regime has not been explored yet. In this research, we present the gapless HgTe quantum well as a versatile platform that hosts two subbands with significantly distinct effective masses. HgTe-based devices offer an exceptional opportunity for investigating transitions between various regimes, as they can be precisely adjusted using gate voltage to control density and system degeneracy.

In the present paper we report the experimental and theoretical study of the transport in a gapless HgTe quantum well with the width of $d_c = 6.3 - 6.5$ nm. In the region where the holes with the linear and the parabolic spectrum coexist (figure 1a), the system lacks the Galilean invariance and we observe resistivity $\rho \sim T^2$ in the fully degenerate and $\rho \sim T^\alpha$ ($\alpha \approx 3$) in a partially degenerate regimes, where the heavy holes obey the Boltzman statistic, while the Dirac holes remain degenerate (figure 1b). Such T dependence is attributed to the mutual friction between the Dirac and the heavy holes. To validate our findings, we compared theoretical predictions with experimental data, revealing a satisfactory agreement. An interesting observation is that within the temperature range of 10-100 K, hole-hole scattering proves to be significantly more influential than impurity scattering [1]. This is an uncommon occurrence, as in conventional metallic systems, particle-particle collisions typically do not limit conductivity.

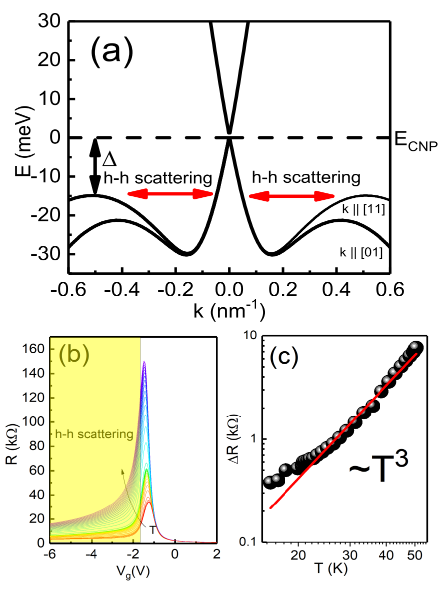

Fig. 1. (a) Schematic representation of the energy spectrum of a 6.4 nm HgTe quantum well. (b) The resistance of the 6.4 nm sample as a function the gate voltage for different temperatures. (c) The excess resistance $\Delta R(T) = R(T) - R(T = 4.2K)$ as a function of the temperature for the total density $N_h = 4 \times 10^{11} cm^{-2}$.

References

[1] G. M. Gusev, A. D. Levin, E. B. Olshanetsky, Z. D. Kvon, V. M. Kovalev, M. V. Entin, and N. N. Mikhailov, Phys.Rev.B, **109** 035302 (2024).